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Design of high road embankments on improved ground

Conception de remblais routiers sur un sol amélioré

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ABSTRACT: This paper presents design problems of embankments higher than 20m which are settled on a weak soil. Design consideration of ground improvement and stability issue are presented followed by case study from south of Poland. In case of such a high embankment the zone of influence could be the most important parameter during analysis. Deep soil investigation needs to be followed by proper laboratory tests.
The results of settlement of well monitored embankment founded on trenchmix panels are compared with the design assumptions. The crucial part of the paper is a study of numerical models parameters influencing the settlement prediction. The study contains the influence of model size and single parameters influence. All the numerical analysis are 3D taking into account trenchmix panels ground strengthening.

RÉSUMÉ:
L'article présente des problèmes de conception des remblais supérieurs à 20 m qui sont installés sur un sol faible. La conception, l'amélioration des sols et la stabilité sont présentées, suivies d'une étude de cas réalisée dans le sud de la Pologne. Dans le cas d'un remblai d'une telle hauteur, la zone d'influence pourrait être le paramètre le plus important lors de l'analyse de conception. Les recherches approfondies sur les sols doivent être suivies d'essais de laboratoire appropriés. Les résultats du tassement du remblai bien surveillé, fondé sur des panneaux trenchmix, sont comparés aux hypothèses de conception. La partie cruciale du document est une étude des paramètres de modèles numériques qui influencent la prédiction de tassement. L'étude contient l'influence de la taille du modèle et de l'influence de paramètres uniques. Toutes les analyses numériques sont prises en compte en 3D en raison du renforcement du sol des panneaux trenchmix.

Keywords: High embankments, improved ground, Trenchmix

1 THE PROBLEM WITH HIGH EMBANKMENT

One of the criteria for the proper design of a road embankment is the reduction of settlements of the embankment and of the soil underneath it. In addition, during the design process, You need to remember about stability and stiffness of the embankment must be ensured. It is important to assess the type of soil foundation and its bearing capacity before building the embankment. In the case of weak soils, before embankments are formed on them, they should be reinforced beforehand.
The paper presents the problem of soil reinforcement, under a high road embankment.

Trenchmix (TRMX) Technology which was used to strengthen the ground.

Figure 1 Picture which show an investition

The publication is based on a case stady of ground reinforcemend under a high embankment located along the S19 expressway(Fig. 1). The investment is located in Rzeszow, in the South – East Poland .

2 GEOLOGY

The designed embankment is located in the valley. On the edge of the valley in subsurface layers lies unstable silty clay. On the remaining part of the slope in the subsurface layers lie soft or very soft silt. In the valley substrate, humus lie in the subsurface layer. Locally in the valley substrate there is located soft or very soft silty clay.

Under the organic soil on depth from 3,1m to 5,5m there is located stiff or firm silt or silty clay. The thickness of this layer varies from 2,0m to 7,0m (Fig. 2)

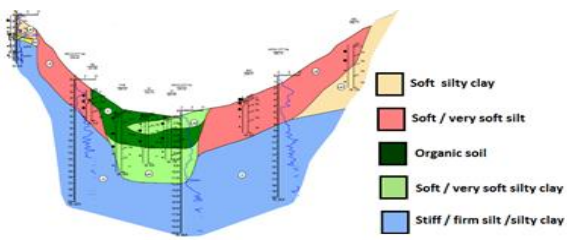

Figure 2 Geology of the reinforced area

Geological documentation was made on the base of archival tests which were included on geological - project documentation. Due to significant changes in the level of the original design assumptions, for the proper design of the route, the soil investigation has been made more detailed

2.1 In - situ testing

In order to correctly define geology, six geological cross-sections were created in the area under the embankment. To create that cross–section, measurements from design documentation and results obtained from additional tests were used. As part of these tests: research holes, CPTu static probes, SLVT shear probes and shear probes with constant shear FVT were implemented.

2.2 Laboratory tests

What is more, laboratory tests were made in order to better define the ground parameters needed to design the high embankment. Samples with undisturbed structure were taken for oedometer tests with consolidation and for triaxial compression testing. The oedometer tests were designed in 5 steps to a maximum pressure 400 kPa. One of most important parameters, from the tests was Young modulus of *krakowiecki* clay, sometimes described as stiff or firm silt or silty clay.. Below a comparison from oedometer tests from two different probes is shown. The results of oedometer tests from two different samples are presented below.(Tab 1)

Table 1 Examples test results from the oedometer for krakowieckie clay

	Probe 1		Probe 2	
Load [kPa]	100-200	200-400	100-200	200-400
M0 [MPa]	5,46	5,25	10,26	13,03
E [MPa]	3,08	2,96	5,79	7,36
ε [%]	4,34	7,16	2,29	3,40

In addition, a clay sample was tested in a triaxial compression apparatus. The results are presented on chart below (Fig. 3). Table 2 under the chart presentes values of Young modulus which are dependent on the value of deformation for different pressure in triaxial compression apparatus.

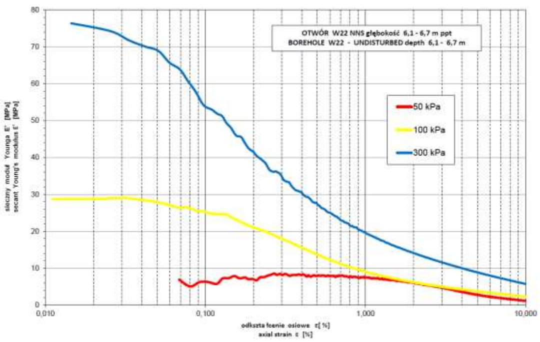

Figure 3 Dependency graph between Young modulus and sample deformation in triaxial compression apparatus.

Table 2 Compare of test results from the triaxial compression apparatus.

Deformation	10%	1%	0,1%
Pressure in the apparatus:100kPa	1MPa	8 MPa	6 MPa
Pressure in the apparatus 300kPa	6MPa	20MPa	54MPa

After analyzing the above results, expecting the deformations in the order of 0.1% - 1% Young modulus for *krakowieckie* clay was assumed as 25 MPa.

In addition, stabilized soils were subjected to triaxial compression testing in order to more accurately determine the slope stability factor and slip surface location. The research was carried out on two soil mixtures with different binders and in different time intervals.

Table 3 Results of strength tests after 28 days

Type of mixture	Effective friction angle [°]	Effective cohesion [kPa]
Soil +binder I	33	5
Soil +binder II	36	29

Table 4 Results of strength tests after 180 days

Type of mixture	Effective friction angle [°]	Effective cohesion [kPa]
Soil + binder I	32	29
Soil + binder II	32	56

Its has been decided to apply Soil+ binder I mixture. One of the aspects that influenced the choice of binder I was the financial issue. For design purposes, a safe estimation of the mixture parameters was made: $\Phi' = 30^o$ and c'=15 kPa.

In addition, the triaxial compression apparatus was used to select the composition of TRMX cement-ground mix. The procedure was similar as in the case of stabilized soils. [1] The results are not included in this paper.

3 TRENCHMIX TECHNOLOGY

The technology that has been proposed to improve the soil under the base of the embankment is Trenchmix technology It consists of deep mixing of soil with binder using a specialist *Trencher* machine.

This is a machine with a tracked chassis with an arm to which a mobile cutter is attached. The arm operates on the principle of a chainsaw (Fig. 4). Trenchmix technology consists in destroying the structure of the ground by the blades on the chain and mixing it with the binding material. In the ground, cement / ground walls / baffles are formed. The equipment allows panels with a width of 0,4m to be produced. The considerable power of the hydraulic motor and the high speed of the cutting-mixing chain allow for achieving high productivity and the ability to work in hard soil. [4] [3]

Figure 4 Trencher used in Trechmix technology

In addition, Trenchmix technology is equipped with a control and recording system that allows you to control the work in real time and register the parameters of the screens. High quality mixing of the ground and the resulting ground–concrete panels is carried out by automatic adjustment of the movement speed of the trencher, the speed of travel and the amount of binding material delivered.

4 CASE STUDY S19

Road embankment along the S19 road in the kilometer from 8 + 110 to 8 + 380 was a major design challenge. The problem was based on poor ground conditions with complex geology and considerable embankment dimensions. The basic criterion during the design was the limitation of the settlement of the ground under the planned embankment. The second factor determining the boundary conditions of the project was the lack of disturbance of the existing water conditions. In addition,analysis of the stability of local and global slip surfaces, which was caused by significant transversal slopes of the area, was required.

During the design, a different layout of the Trenchmix panels was considered. The arrangement of panels transversely to the road axis was considered to be the best solution. A longitudinal layout of the panels or grate could cause accumulation of groundwater, which would result in water pressure on the TRMX panels. The spacing and the length of the panels have been adjusted to the water and ground conditions as well as to the arrangement of the level of the road. The interval of the panels varied from 2m to 3m. Arrangements of panels was dependent on the embankment height. The length of the panels varied from 6m to 10m. Decision about panel width was dependent on the stresses involved on the panel. It was decided that in order to unify the width, in relation to the maximum stresses, a panel width of 40 cm was assumed. A cross-section of the designed embankment is presented below on figure 5

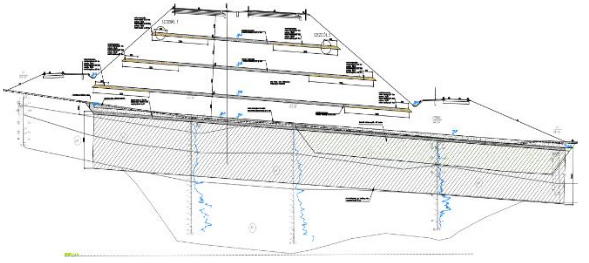

Figure 5 Cross-section of the designed embankment

At km 8 + 150 to 8 + 270 under the right embankment slope, the decision was taken to make partial ground exchange to a depth of 4.5m. This action was dictated by the concern that the cement-ground panels created in the native organic soil located there would not obtain adequate compressive strength.[2]

The reinforcement was topped with a 70 cm thick transmission layer made of coarse crushed aggregate. In the stabilized embankment material, compensating inserts were used to prevent too much stiffnes of the soil masses in the embankment, and to alleviate the negative impact of the settlement of ground on the embankment.

In addition, it was found that to allow the pore pressure to be dispersed in the soil, the embankment should be built no faster than 0.5m/week.

During the implementation process, as with the initial assumption checking the quality of panels, the expected compression strength of the TRMX panel was assumed in relation to the type of reinforced soil and the amount of binder used. It was assumed that TRMX panels after 90 days should have compresive strength equal to 2.5 MPa, the control condition for the strength increase was the strength achieved after 56 days, equal to 2MPa. The strength values obtained after 56 days ranged from 2.48 MPa to 11.82 MPa. However, the value of strength after 90 days ranged from 2.8 MPa to 12.07MPa. The highest values of strength were obtained from the area where the ground was replaced.

5 MONITORING

To check the design assumption a profilometer casings have been installed, a picture from the instalation is shown on figure 6. They have allowed for the estimation of soil settlements under the embankment. Graphic representation of the results are shown on figure 7 (below).

Figure 6 Profilometer profile instalation

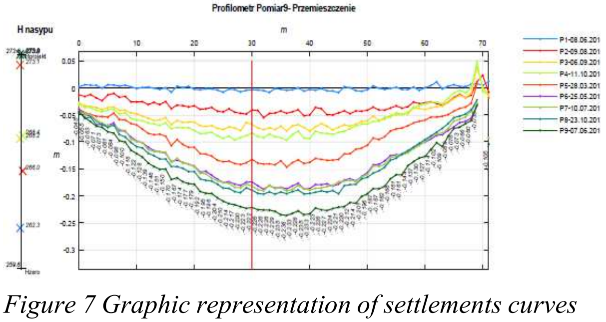

Figure 7 Graphic representation of settlements curves

For the measurements, the Digital Hydrostatic Profile Gauge, manufactured by Soil Instruments Ltd. has been used. It consists of a profilometer probe which has been placed in a nylon tube filled with hydraulic medium. The measurement system has been equiped with a digital pressure sensor fixed to a roll. The roll has been equiped with a bluetooth transmiter which enable data to be sent to the computer.

The measurement results have been used to perform back analysis, the aim of which was to gain knowledge needed for future implementation.

To gain additional information regarding 3D behaviour of the bridge and embankment a 3D laser scan has been performed . Collected data in a form of points cloud have been imported into a 3D modeling software to display the displacements (figure 8). The comparison of predicted and measured behaviour of the bridge is not shown in this paper.

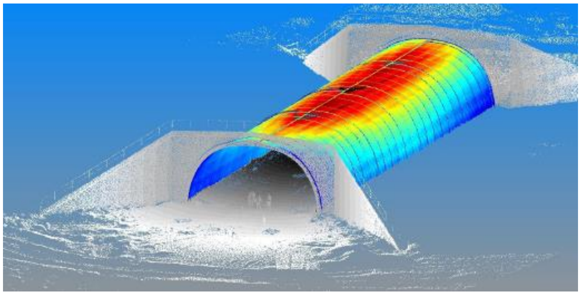

Figure 8 3D model showing the displacement

6 ANALYSIS OF MONITORING RESULTS

Taking advantage of collected and interpreted settlement results, a back analysis has been made. Because the system is periodical (TRMX panels and subsoil) the use of a 3D model has been chosen. A plane of symmetry has been used to establish the model thickness which was equal to 0,5 of TRMX panel and 0,5 of the panels spacing. A model of both sides is shown on figures 10 and 11. The Z-Soil software has been used for the analysis.

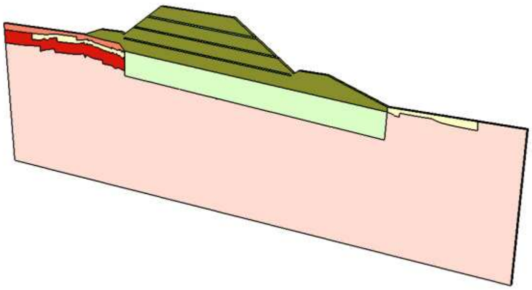

Figure 9 Z_Soil 3D model view (TRMX panels side)

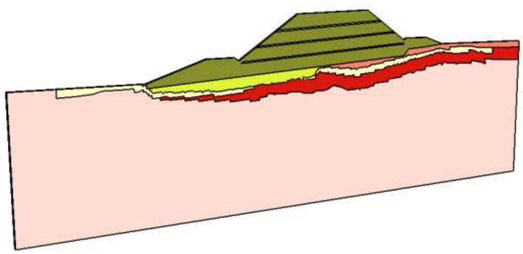

Figure 10 Z_Soil 3D model view (subsoil side)

The back analysis contained from 3 stages:
1) 1) Analysis of the influence of model high on the settlement prediction
2) Verification of the embankment stiffness on the settlement
3) Ascertainment of the influence of *krakowiecki* clay Young modulus on the displacements. The analysis at this stage has been performed iteratively to find the best match between the monitoring results and diplacement in the model.

In the begining of the analysis a 'base model' was created. In each of the stages only one parameter has been modified – model height or embankment stiffnes or clay Young modulus. The results were compared on the level of the profilometer line. Numerical analyses have shown that this was not the location of maximal settlement. The most important parameters of the model are listed below and in the table 5:

Model heigth: ~2,5H = 50m
where H- embankment heigth measured in the embankment axis equal to 21 m

Table 5 Parameteres of the layers used in the model

	ϕ' [°]	c' [kPa]	E [MPa]
Clay	28,5	0	25
Silty clay	34,5	3	16
Embankment	30	15	875
TRXM panel	-	-	140

Stage I – influence of model depth

For the purpose of analysis four different model heigth have been chosen 1,5H, 2H, 2,5H and 3H. For each model the calculated displacement have been compared to monitoring results. However in the paper only settlements from the last measurement are compared and shown.
On a larger scale, the depth problem of the model is discussed in [6].
In figure 12 the results of analysis are plotted. Real settlement measurement result are shown using the horizontal line. The settlements values calculated in different models are plotted in a form of curve which shows the trend. As a conclusion, figure 11 shows that the nearest to the measured values is the model whose depth is equal to 1,5H. The difference betweent he highest and lowermost model is in the range of 27%.

Figure 11 Influence of model heigth

Stage II – embankment material stiffnes

The second stage consisted of changing the Young modulus of the embankment material. As the whole embankment was built from stabilized soil the measured parameter was the uniaxial compressive strength (Rc). Based on this value using correlations for DSM [5] the Young modulus (E) was estimated. There were 5 values of each parameters:`

- Model I: Rc = 0,23 MPa E=80 MPa
- Model II: Rc = 1,25 MPa E=438 MPa
- Model III: Rc = 2,5 MPa E=875 MPa
- Model IV: Rc = 5,0 MPa E=1750 MPa
- Model V: Rc = 7,5 MPa E=2625 MPa

Analogical as in stage I the comparison of each measurement result have been made but only the last one is shown in this paper. Figure 13 shows a the influence of Rc (and E) value on the results. Analysing the results on the graph it can be observed that only model 1 shows significantly higher settlement. In case of other models the difference is inconsiderable. This observation is significant from the execution point of view, while the required stiffness influences cement quantity needed to be added during soil stabilization.

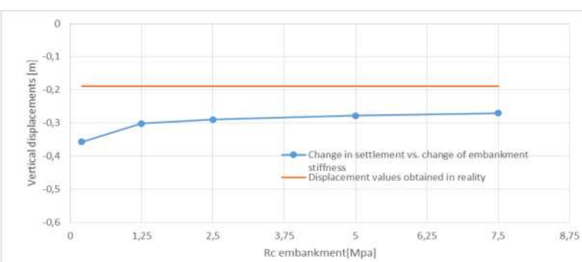

Figure 12 Influence of embankment material stiffness

Stage III – influence of „krakowieckie clays" stiffness

As it can bee seen on figures 10 and 11 the clay was under the whole model. Other soils were within the depth of TRMX panels so most probably their stiffness was not crucial. The aim of the analysis was to show the influence of clay Young modulus. What needs to be added is that the height of this layer is quite significant (about 40m for th base model). In case of used constitutive law (Mohr–Coulomb) there is a need to use only one modulus while real soil modulus is stress and strain dependent.

After extensive analysis (changing Young modulus) 4 models have been used to how the trend. In this models E of values equal to: 12,5 MPa, 25MPa, 50MPa , 125MPa have been used. To show the comparison results for the last monitoring measurements, graphs shown on figure 14 have been plotted. Quite high results dependance on Young modulus can be seen. The value of E=50MPa shows best fit with the monitoring results. Looking at the edometric and triaxial tests results it can be seen that such a high modulus was measured only in Triaxial aparatus for strains in the range of 0,1%. The design assumption of E=25MPa and strains 0,1-1,0% seems to be reasonable and safe.

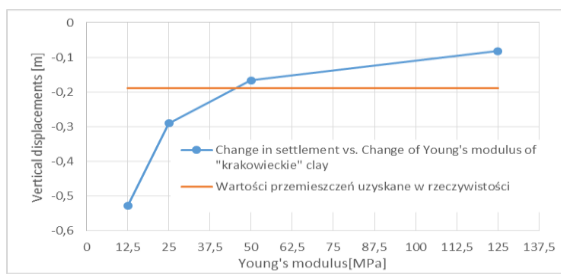

Figure 13 Influence of clay stiffness

Separately from 3 stages described before, displacement maps have been analysed. Two of them are shown on figures 15 and 16. It can be seen that the TRMX panel do not behave totaly stiff. The material is semi - stiff and therefore the maximum settlements are within the range of TRMX panels. It is an interesting finding that the maximun settlements are not located below the panels.

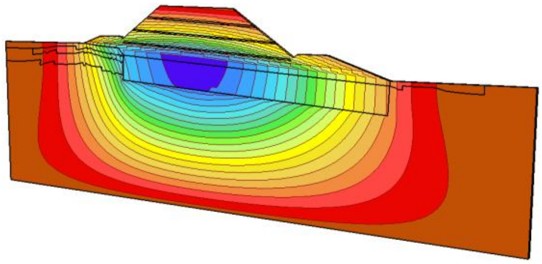

Figure 14 Examplary settlements map (TRMX panels side)

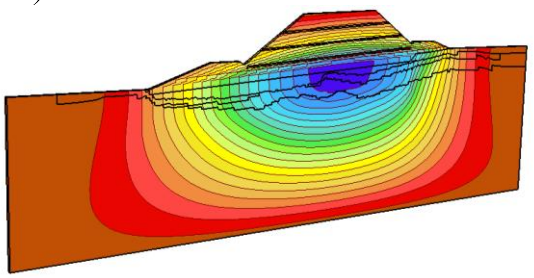

Figure 15 Examplary settlements map (subsoil side)

7 SUMMARY AND CONCLUSION

Summing up from the above analysis, it can be concluded that the key parameter of the project was the Young's module of the last layer. Due to the fact that the ground, which was under the TRMX reinforcement were mainly *krakowiecki* clays, their stiffness was of the greatest importance for settlement of the whole embankment. When designing such a high embankment, it is necessary to come to terms with its limited settlement. To predict it better, it would be necessary to perform more precise tests in the edometric apparatus, with higher pressures. A higher load would allow for a better representation of clay behaviour in deeper layers of the ground. Additionally, it should be noted that the influence of stiffness of the embankment after reaching Rc = 1. 25 MPa on the value of settlement below is negligible. This means that it is not necessary to achieve higher compressive strength of the embankment in the context of soil settlement underneath the embankment

8 LITERATURE

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